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The effect of physiological age of potato plants on chosen chlorophyll fluorescence parameters

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ABSTRACT

Potato (*Solanum tuberosum* L.) crop is the world's number one non-grain food commodity and the fourth main food crop in the world after maize, rice and wheat. It is a typical plant mainly of temperate climate. Chlorophyll *a* fluorescence kinetics is an informative tool for studying the effects of different environmental stresses on photosynthesis. The aim of this work was to study the response of selected potato cultivars to meteorological conditions during the growing season and physiological age of plants using chlorophyll *a* fluorescence parameters. The pot experiment was carried out over the course of 2 years with six early cultivars. Chlorophyll *a* fluorescence measurements were performed on the plants with a Pocket plant efficiency analyzer determined parameters were: F_v/F_m (the ratio of variable to maximal chlorophyll fluorescence) and PI (the performance index of photosystem II). In total 2040 measurements of each parameter were made. Final harvest was performed after full maturity of plants. The results of the experiments were analysed with ANOVA. Changes of chlorophyll *a* fluorescence parameters in terms of physiological age were analysed using polynomial regression model. A significant negative correlation between the maximum air temperature and PI parameter was found as well as a significant negative correlation between physiological age of potato plants and both chlorophyll *a* fluorescence parameters.

Keywords: abiotic stresses; high temperature during growing season; modelling; plant pigment

The potato (*Solanum tuberosum* L.) crop is the world's number one non-grain food commodity and the fourth main food crop in the world after maize, rice and wheat (FAO 2014). Potato is a typical plant mainly of temperate climate. The limits and optimal values for the growth of the above-ground part of the potato plant and for the tubers are different. From experiments conducted in growth chambers it is known that haulm growth is fastest in the higher temperature whereas the optimal range for tuberisation and tuber growth is lower (Rykaczewska 2015). Under high-temperature conditions, tuberisation is significantly inhibited and photoassimilate partitioning to tubers is greatly reduced (Lafta and Lorenzen 1995). Heat stress due to increased temperature is an agricultural problem in many areas in the world (Birch et al. 2012). Transitory or constant high temperatures cause an array of morpho-anatomical, physiological and biochemical changes in plants, which affect plant growth and development and may lead to a drastic reduction in economic yield (Wahid et al. 2007). The adverse effects of heat stress can be mitigated by developing potato plants with improved thermotolerance using various genetic approaches (Veilleux et al. 1997). For this task, however, a thorough understanding of physiological responses of potato plants to high temperature is imperative. An informative tool for studying the effects of different environmental stresses on photosynthesis is the chlorophyll *a* fluorescence kinetics (Strasser et al. 2000, Kalaji et al. 2012). In the research work the chlorophyll fluorescence techniques are used for assessment of potato genotypes tolerant and sensitive to environmental stresses (Jefferies 1992, Mauromicale et al. 2006, Ierna 2007). However, the physiological age of plants may also have a significant role (Mauromicale et al. 2006, Ierna 2007, Rykaczewska 2015). The aim of this work was to study the response of the chosen potato

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cultivars to meteorological conditions during the growing season and physiological age of plants using two chlorophyll *a* fluorescence parameters.

MATERIAL AND METHODS

The pot experiment was carried out in an open area next to a greenhouse over the course of 2 years 2010–2011 in Jadwisin (52°30'N, 21°04'E), Poland. The following early cultivars were tested: Flaming (very early), Aruba, Etola (early), Finezja, Tetyda (medium early) and Desirée (medium early) with high adaptability to the environment (EPCD 2015). Weather conditions during the years of study were monitored using a Campbell weather station (Campbell Scientific Inc., Logan, USA) located adjacent to the greenhouse and additionally using a thermohygrograph placed between pots.

In the spring, potato minitubers of the size 3–4 cm (transverse diameter) were pre-sprouted for 5 weeks and used for planting. They were planted in 10-L pots with a thin layer of gravel and filled with soil which is the standard substrate for vegetables. The number of pots totalled 30, and each cultivar accounted for 5. Dates of planting were April 22–23. The pots with plants were set on special tables on wheels and were moved outdoors, adjacent to the greenhouse. At times of rainfall they were transported under roofing. Throughout the growing season the plants were carefully tended daily and regularly watered at a level close to optimum. Soil moisture was measured using the soil moisture meter (Bioterm 812, Poland). Recommended plant protection products were used to control diseases and pests.

Chlorophyll *a* fluorescence measurements were performed on the plants with a Pocket PEA (plant efficiency analyser, Hansatech, UK). The youngest full expanded leaves were kept in darkness for at least 20 min in specially provided clips. Determined parameters were: F_v/F_m – the ratio of variable to maximal chlorophyll fluorescence (the photochemical efficiency of photosystem II) and PI – the performance index of photosystem II (Strasser et al. 2000). Measurements were made on weekdays from 7:30–9:00 a.m. with saturation irradiance up to 3500 μmol/m^2/s. Dark adaptation time was the time needed to obtain a steady value of F_v/F_m. The period of measurements lasted from the end of plant emergence and production of leaves of the right size until the early stage of plant maturity. Number of measurements and days after planting are presented in Table 1. In total 2040 measurements of each parameter were made. Final harvest was performed after full maturity of plants, between August 5 and 19.

The results of the experiments were analysed using ANOVA with Statistica 12 computer program (StatSoft 2014). Means were separated with the Tukey's contrast analysis at significance level 0.05. Changes of chlorophyll *a* fluorescence parameters in terms of physiological age were analysed using polynomial regression model:

$$y = \beta_0 + \beta_1 x + \beta_2 x^2$$

Where: $\beta_{0 \cdots 2}$ – regression model parameters; y – chlorophyll *a* fluorescence parameters; x – physiological age in days after planting (number of measurements).

RESULTS AND DISCUSSION

In the present work the measurements of chlorophyll *a* fluorescence were performed using a pocket plant efficiency analyser (Pocket PEA), by means of which it is possible to determine only two parameters: F_v/F_m and PI. The choice of

Table 1. Number of measurements of chlorophyll *a* fluorescence parameters and days after planting (DAP), mean value for years

Number	DAP	Number	DAP
1	31	18	61
2	33	19	63
3	34	20	64
4	37	21	66
5	38	22	69
6	40	23	70
7	43	24	72
8	45	25	73
9	46	26	75
10	47	27	77
11	49	28	79
12	50	29	80
13	53	30	82
14	55	31	84
15	57	32	85
16	58	33	86
17	60	34	90

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Table 2. Mean values of daily air temperature and photosynthetically active radiation (PAR) during growing season in the years of study

Meteorological factor	Year	Month				Mean
		May	June	July	August	
Temperature (°C)	2010	12.3	16.8	20.0	18.5	16.9[a]
	2011	13.1	17.5	17.0	17.5	16.3[a]
	mean	12.7[b]	17.1[a]	18.5[a]	18.0[a]	16.6
PAR ($J/m^2/s$)	2010	265	420	399	332	354[a]
	2011	384	429	380	340	358[a]
	mean	325[a]	424[a]	339[a]	336[a]	356

[a,b]Mean values followed by the same letters are not significantly different at the 0.05 level according to the Tukey's test

instrument was deemed to be appropriate due to the fact that we wanted to explore the possibility of practical application of chlorophyll fluorescence in the future to evaluate a large number of potato genotypes in terms of their tolerance to high temperatures and drought during the growing season. Parameter F_v/F_m is the most reliable for the definition of genotype differences (Ierna 2007). However, the parameter PI gave a clear picture of the physiological status of potato plants at the moment of measurement (Strasser et al. 2000, Kalaji et al. 2012). This integrative parameter reflects the functionality of photosystem II and gives us quantitative information on the current state of plant performance under stress conditions (Živčák et al. 2008).

Pearson correlation between meteorological factors and physiological age of plants and chlorophyll *a* fluorescence parameters. In our study the two most important meteorological factors, air temperature and the photosynthetically active radiation, were similar in the years of study and favourable for potato development (Table 2). However, the maximum air temperature was negatively correlated with parameter PI (Table 3). These results confirm the view that temperature is a very important factor influencing photosynthesis and yield of potato plants (Levy and Veilleux 2007) even in years with the weather conditions very favourable for potato development. Pearson correlation coefficients indicated a significant negative correlation between physiological age of potato plants and both chlorophyll *a* fluorescence parameters: F_v/F_m and PI. This problem was pointed out earlier by Hong et al. (1999).

Table 3. Pearson correlation coefficients between meteorological factors of the years of study and physiological age of potato plants and chlorophyll *a* fluorescence parameters at the significance level $P < 0.0001$ ($n = 2040$)

Meteorological factor/ physiological age of plants	F_v/F_m	PI
Photosynthetically active radiation	–0.20324	–0.30087
Maximum air temperature	–0.25973	–0.42247***
Minimum air temperature	–0.13073	–0.24051
Physiological age of plants	–0.37003***	–0.63920***

F_v/F_m – ratio of variable to maximal chlorophyll fluorescence; PI – the performance index of photosystem II; ***$P < 0.0001$

Chlorophyll *a* fluorescence parameters depending on cultivar. Values of F_v/F_m of the tested

Table 4. Chlorophyll *a* fluorescence parameters and yield depending on cultivar (mean of two years)

Cultivar	F_v/F_m	PI	Yield (g/plant)
Flaming	0.8029[ab]	3.4951[bc]	1440[ab]
Aruba	0.7955[bc]	3.9653[a]	1344[ab]
Etola	0.7953[bc]	3.8108[a]	1260[ab]
Finezja	0.8048[a]	3.8108[a]	1373[ab]
Tetyda	0.7944[c]	3.2654[c]	1508[a]
Desirée	0.8004[abc]	2.8929[d]	1309[ab]
Mean	0.7989	3.4934	1372
2010	0.7935[b]	3.3641[b]	1374[a]
2011	0.8043[a]	3.6227[a]	1370[a]
F	***	***	**

The same letters mean a lack of significant differences at $P \leq 0.05$ according to the Tukey's test. *F* – probability values: **$P \leq 0.01$; ***$P \leq 0.001$; F_v/F_m – ratio of variable to maximal chlorophyll fluorescence; PI – performance index of photosystem II

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Table 5. Parameter estimation, models *F*-statistics and coefficients of determination of estimated polynomial regression models – for all tested cultivars

Polynomial regression parameters	F_v/F_m			PI		
	parameter estimation	models *F*	R^2	parameter estimation	models *F*	R^2
β_0	0.81269			7.39965		
β_1	0.00184	220.34**	0.1771	–0.30492	716.59**	0.4124
β_2	–0.00011			0.00355		

βo – intercept; β_1 – 1st degree regression coefficient; β_2 – 2nd degree regression coefficient; ***P* = 0.01; F_v/F_m – ratio of variable to maximal chlorophyll fluorescence; PI – performance index of photosystem II

cultivars presented a relatively high level (Table 4). Averaged over measurement date the F_v/F_m was the highest in cv. Finezja, intermediate in cvs. Flaming, Desirée, Aruba, Etola and lowest in cv. Tetyda. The largest difference among cultivars (Finezja and Tetyda) was only 1.3% and between the years of study 1.4%. The performance index of photosystem II (PI) gave a clearer picture of the physiological status of plants at the time of growing season. The differences among cultivars were up to 27%. The difference between the years of study was only 7.7%. Averaged over measurement date the PI parameter was the lowest in cv. Desirée with very high adaptability to the environment. Ahn et al. (2004) also indicated a lack of tolerance of cv. Desirée to high temperature during the growing season. Despite this, in the current research on the biochemical and genetic tolerance of potato plants Desirée is used as a cultivar with resistance to heat stress (Hancock et al. 2014). It therefore remains yet to clarify whether the cv. Desirée may be a model cultivar in studies of tolerance to heat and drought stress during the growing season.

Chlorophyll *a* fluorescence parameters depending on physiological age of potato plants. The polynomial regression between the values of both tested chlorophyll *a* fluorescence parameters and physiological age of plants was calculated (Table 5). Significant values of the *F*-statistic demonstrate an adequate fitting function and its significant character. During most of the growing season parameter F_v/F_m remained at a high level and for the tested cultivars averaged over 0.8 (Figure 1). Starting from the 25th measurement its value began to decline and reached the lowest level in the end of growing season. The value of PI parameter decreased throughout the growing season on average from 7.5 to about 1.0 (Figure 2).

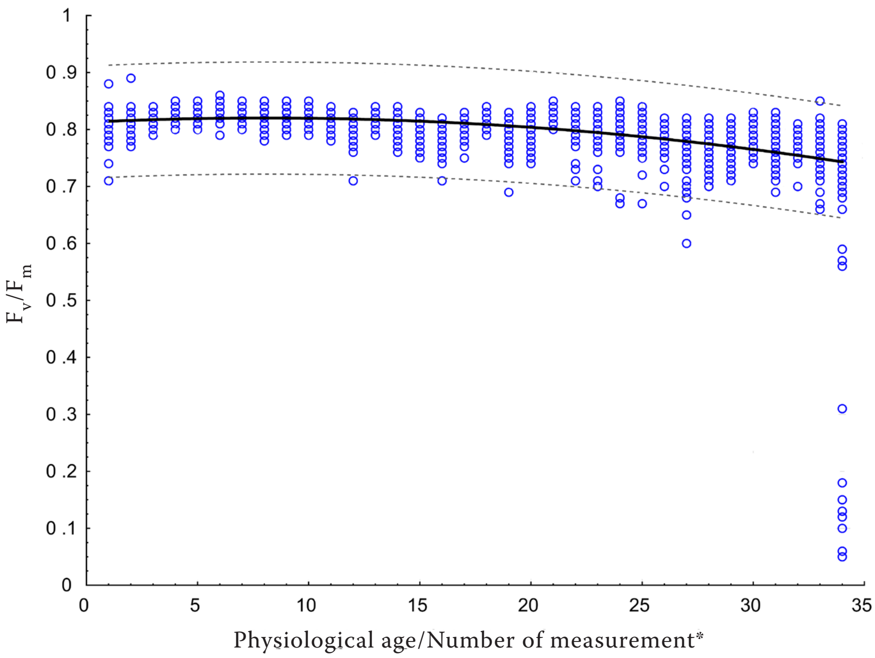

Figure 1. Parameter the ratio of variable to maximal chlorophyll fluorescence (F_v/F_m) depending on physiological age of plants – regression for all tested cultivars. *see Table 1

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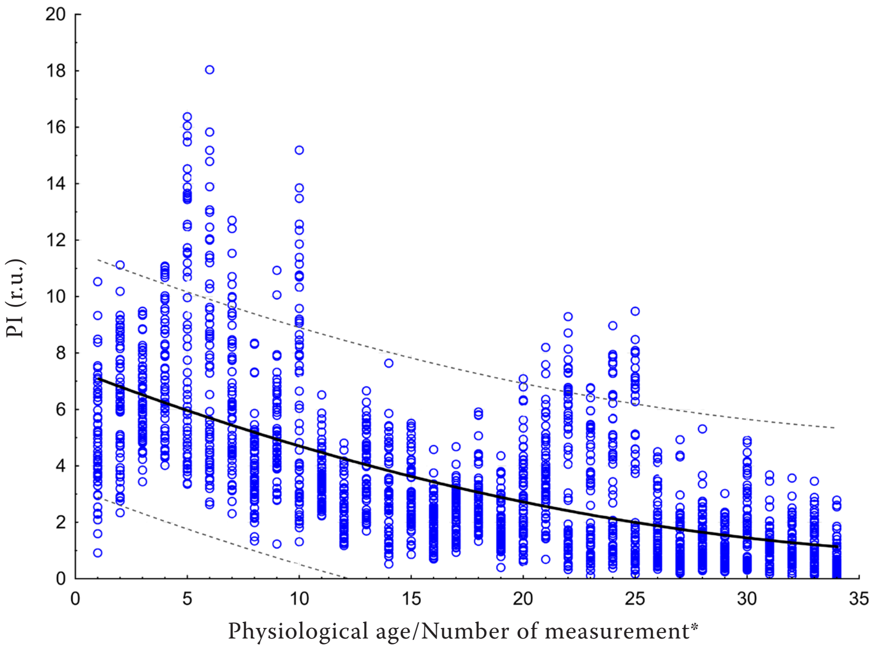

Figure 2. Parameter the performance index of photosystem II (PI) depending on physiological age of plants – regression for all tested cultivars. ru – relative unit. *see Table 1

The results obtained confirm the results of previous studies in the same cultivars where during the flowering period PI value averaged 2.01, in the period of fruit development 1.78 and at the beginning of plant maturation 0.63 (Rykaczewska 2015). Decline in this parameter in the case of potatoes coincides with the period of increasingly intensive transport of assimilates from the leaves to the tubers, which begins at the time of plant flowering.

Correlation between chlorophyll *a* fluorescence parameters and tuber yield. Tuber yield in cv. Tetyda was significantly the highest in cvs. Etola, Desirée, Aruba, Finezja and Flaming it was lower without significant differences among them (Table 4). A significant correlation between F_v/F_m and PI parameters was found (Table 6). However, a correlation between F_v/F_m and yield was not found. Tuber yield was negatively correlated with PI. It is connected with the fact that temperature higher than optimal intensified development of the aboveground part of plants and tuberisation is significantly inhibited (Lafta and Lorenzen 1995). This is confirmed by the results of our previous studies, where it was found that under higher temperature the plants of all cultivars responded with an increase in height (Rykaczewska 2013, 2015).

Table 6. Correlation coefficients between chlorophyll *a* fluorescence parameters and tuber yield (n = 60)

Tested parameter	F_v/F_m	PI	Tuber yield
F_v/F_m	1.0000	+0.3252*	–0.1116
PI	+0.3252*	1.0000	–0.4184**
Tuber yield	–0.1116	–0.4184**	1.0000

*$P \leq 0.05$; **$P \leq 0.01$; F_v/F_m – ratio of variable to maximal chlorophyll fluorescence; PI – performance index of photosystem II

General remarks. Based on the presented investigations and literature review it can be stated that chlorophyll fluorescence is a very sensitive probe of the physiological status of leaves, which can provide very rapid assessment of plant performance in a wide range of situations. However, in the case of potato, and the assessment of plant responses to the stress, the period of measurements is very important. In the earlier period of the growing season, when plants are physiologically younger, high values of PI parameter can be relatively high, despite the impact of stress on them. Therefore, before the implementation of discussed non-invasive techniques for potato genotype screening, it is necessary to conduct more studies.

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